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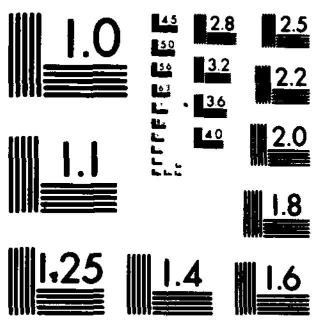

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ELECTROSTATICS 1979

Dr. I. Kaufman

28 November 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers a 2 1/2 day conference on problems related to Electrostatics, held at St. Catherines College of Oxford University. Subjects discussed were Industrial Electrostatics; Electrostatic Hazards; Electrostatics and Fluids; Electrostatic Behavior of Solids, including contact charging phenomena; Measuring Techniques; and Atmospheric Electricity. Five invited and 31 contributed papers were presented. Subjects discussed ranged from modeling of processes leading to electrostatic discharges to practical means of minimizing charging of jet fuel.

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ELECTROSTATICS 1979

On reading the announcement of an Institute of Physics Conference on Electrostatics, to be held at St. Catherines College, Oxford, my immediate reaction was: "Didn't Smythe solve all the electrostatics problems of interest?" (See W.R. Smythe, *Static and Dynamic Electricity*, 3rd ed. McGraw Hill, 1968). Next came visions of Oxford scholars in cap and gown demonstrating in 500-year-old buildings how to solve those difficult problems of Sir James Jeans' 1908 volume, *The Mathematical Theory of Electricity and Magnetism*. (After all, even New College at Oxford is currently celebrating its 600th anniversary.

It was all wrong of course. St. Catherines, a brand new college, is built of glass, steel and concrete; no one wore a cap and gown; and there was very little in the way of problem solving of the Symthe-Jeans variety.

The problems that were actually considered ranged from Xerography to mining the moon, from electrostatic powder deposition to lightning. Perhaps most startling to me was the involvement of electrostatics in an accident, as follows: The brakes of a new type of airplane were being tested by accelerating the plane on the runway and then stopping quickly. After several repetitions of this procedure, the plane exploded. An electrostatics problem? Yes; investigations revealed that during the start/stop maneuvers the fuel tank had contained only a small amount of fuel. Moreover, there was no additive in the fuel for minimizing triboelectric charging, and the tanks were so large that the fuel was able to slosh around over long distances and thus acquire a high enough charge to cause electrical breakdown of the air and the explosion.

Clearly electrostatics considerations can become very practical ones.

Since finding solutions to problems of this type is the mission of the Electrostatics and Applied Physics Unit (EAP) of the Culham Laboratory, and since Culham, the institution that is the center for plasma physics and fusion research in Britain, is only a few miles from Oxford, Conference activities got under way with an official tour of this establishment.

EAP, led by Dr. John Butterworth, performs contract research on a variety of electrostatics problems. Examples are investigations aimed at overcoming ignition hazards from electric sparking in dirty oil tanks that are being washed with high-pressure water jets, the development of field measuring instruments and triggered photography for use in hostile environments, radio-frequency

spark analysis techniques, atmospheric pollution control, and the development of charged-metal-droplet deposition and of ion beam spraying for ion beam lithography and epitaxial material deposition. (During the course of the conference I found out that several other public institutions in the UK also perform consulting work on electrostatic problems. Two of these are the Wolfson Electrostatics Unit of the Department of Electrical Engineering, Univ. of Southampton, and Industrial Development, Bangor Ltd., of the Univ. College of North Wales.)

The formal part of the Conference commenced on the day following our visit to Culham. Of the approximately 110 participants, 40% were from the UK; most of the rest were from Western Europe. There was a handful of representatatives from the US, Canada, Hungary, and Japan.

The five formal sessions extended over 2 1/2 days. Brief descriptions of some of the topics treated follow.

In the session entitled Industrial Electrostatics, P. Keith Watson (Xerox Corp. Rochester, NY), who humorously called the copy machine the "ultimate electrostatic hazard," had been invited to review the scientific basis of electrophotography. He talked of two stages that characterize the electrophotographic processes: (1) The formation of a latent electrostatic image by a photoconductor (now well understood) and (2) Characterization of the development process (still in a somewhat empirical state). He discussed what is now know about these processes and the techniques that have been used to acquire this knowledge.

Among the contributed papers of this session, Sampuran-Sing, J.F. Hughes, and A.W. Bright* (Department of Electrical Engineering, Univ. of Southampton, UK) discussed image-intensified photographic examinations and laser anemometry of the process of powder coating. They found that during the charging of the powder by a corona discharge only a small fraction of the corona ions actually charge the powder. The others, however, are also attracted to the workpieces, where they may be trapped in the deposited layer. As a result, large electrostatic fields can develop in the powder that give rise to "moon craters" or pinholes or that simply modify trajectories of powder particles and therefore lead to poor transfer efficiencies.

The problem of unwanted electrical charging during manufacture of non-conducting films (e.g., photographic film) was the subject of a theoretical paper by K.L. Clum (Eastman Kodak Co., Rochester, NY) and of experimental investigations by J.F. Hughes and A.M.K. Au (Department of Electrical Engineering, Univ. of Southampton, UK) and A.R. Blythe (Imperial Chemical Industries Ltd., Welwyn

*Please see Appendix

Garden City, Herts, UK). The experimental results revealed that the onset point of sparking correlated well with the theoretical predictions made earlier by Horvath and Berta (T. Horvath and I. Berta, "Mathematical Simulation of Electrostatic Hazards," *Institute of Physics Conference Series,* No. 27, 1975; Chap. 4.) See sketch of Fig. 1 (a).

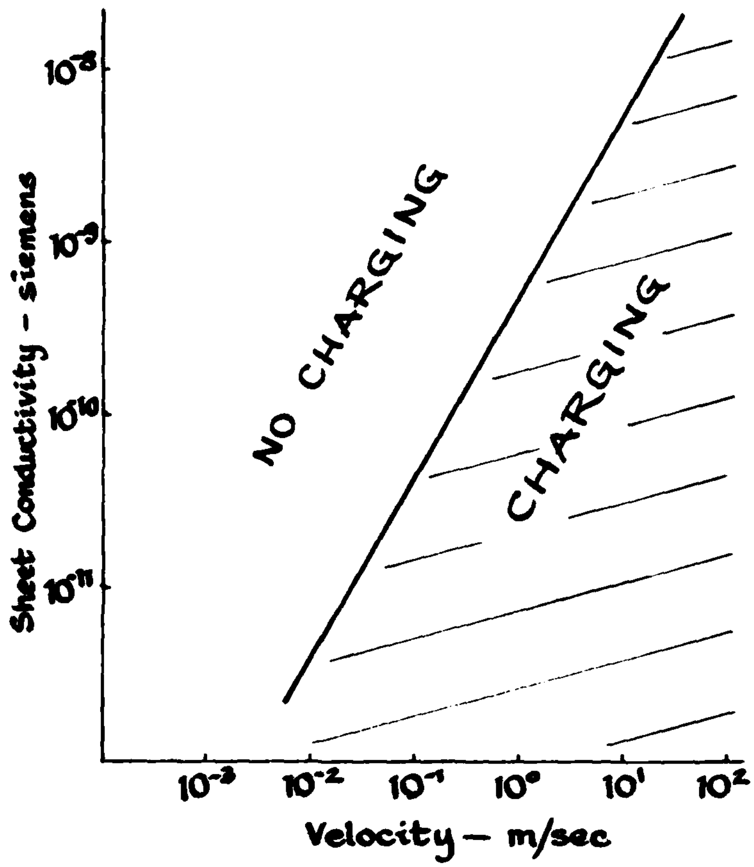

Figure 1(a)

In the experiments, sparking occured at the specific point shown in Figure 1(b).

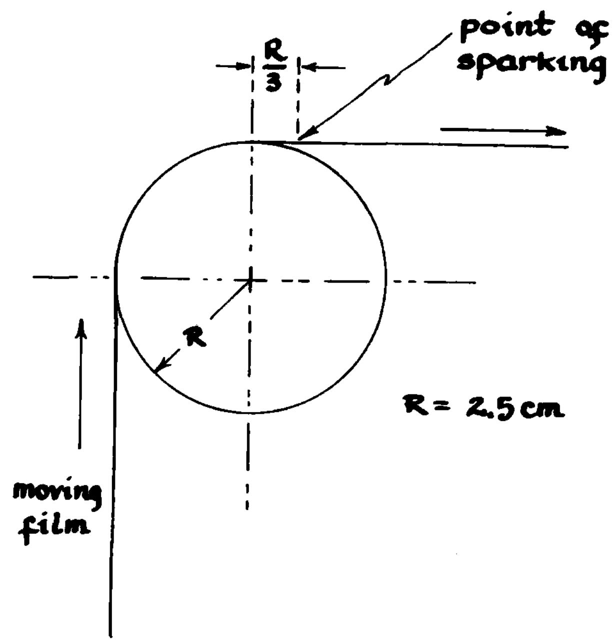

Figure 1(b)

Location of sparking for R = 2.5 cm

Electrostatic dust precipitation has been in use for many years, but only for installations that can be accompanied by a high-voltage power supply. Portable dust filters, such as those in face masks or vacuum cleaners, usually rely solely on mechanical filtration by fibrous material. Efficient filters have the disadvantage of imposing high resistance to the air passing through them. This may all be changed by the nonwoven electret fiber filters discussed by J. van Turnhout and J.H.M. Albers (TNO, Division of Technology for Society, Delft, The Netherlands) and W.H. Hoeneveld, J.W.C. Adamse, and L.M. van Rossen (N V Verto, Rotterdam, The Netherlands). Since charges are "built in" these electrets, no power supply is needed. The authors described a method of large-scale production of polypropylene electret fibres, a method for processing these into high-efficiency low-resistance filters, the mechanism of capture of both charged and uncharged particles

of less than 1-μm diam., and very optimistic performance characteristics of practical filters.

From earthly dust to mining the moon: Here I.I. Inculet (Univ. of W. Ontario, Canada) and D.R. Criswell (Universities Space Research Association, Houston, Texas) focused their attention on space solar power stations that could be constructed for beaming microwave power to the earth. Such stations will require large quantities of material. Since the cost of sending 1 kg of material into orbit from the earth vs. from the moon presently is in the ratio of 25 to 1, the authors concluded it would be advantageous to extract many of the necessary materials from the lunar surface and discussed the refining of materials by lunar electrostatic ore separation and processing, a technique which they claimed will have financial advantages over terrestial materials for space solar power station construction.over terrestial materials.

In the session entitled Hazards, J.T. Leonard, in an invited paper prepared together with W.A. Affens (both from Naval Research Laboratory, Washington, D.C.) discussed problems encountered with aircraft fuels. Some military aircraft are filled with reticulated plastic foam which acts as a three-dimensional flame arrestor for suppressing ignition of fuel vapor by incendiary projectiles. Although acting as a flame retarder, this foam may charge the fuel by contact electrification sufficiently to cause a spark and an explosion.

Leonard presented results with various types of foam, fuel, and additives. He pointed out that the degree of charge acquired is a sensitive function of material composition. Thus, for the same fuel, charging for a polyether foam was about six times greater than for polyester foam. The general conclusion was that the charging problem is very important and requires careful preventive measures, such as additives for increasing fuel conductivity. Finally, Leonard almost destroyed my faith in the CO_2 fire extinguisher by stating that the CO_2 passing through an extinguisher horn could generate enough charge to cause it to become a spark ignitor.

Among the contributed papers, a different aspect of airplane operation was discussed by J. Taillet (Office National d'Etudes et de Recherches Aérospatiales, 92320 Chantillon, France): the standardization of procedures for testing aircraft charging phenomena in the laboratory, the factory, and the field, to protect against disturbances of communication and navigation signals by corona discharges and sparks. This includes the design of special instruments, methods of implementation, and complete test procedures.

Among other talks in this session there were discussions of ignition criteria in electrical breakdown (e.g., airborne suspensions of dust require minimum ignition energies of about 5 mJ), ignition problems in filling vessels with powders that have become charged, attempts to use Fourier spectrum analysis of the pulses radiated by a discharge in a hostile environment for precise location of the discharge (because the geometry of the discharge point influences the spectrum), and theoretical and experimental studies of the mechanism of discharge formation.

The invited paper in a session dealing with fluids was by J.C. Gibbings (Department of Mechanical Engineering, Univ. of Liverpool, UK). Entitled "Interaction of electrostatics and fluid motion," it dealt with the existing knowledge and with gaps in the knowledge of this subject. This rather sophisticated paper treated and combined concepts in the fields of electrostatics, physical chemistry, and fluid dynamics, and reviewed the work on charge behavior associated with flow of a number of individuals. Gibbings stated that a large part of his work has dealt with impure liquids or, as he called them, "liquids with muck." He also discussed a model for the phenomena of flow through a filter. His general conclusions were that a large amount of work on interactions of electrostatics and fluids remains to be done in order to understand the details of fluid flow in chargeable liquids.

Concurring with the observations of Leonard, above, G.J. Butterworth, in "Electrostatic ignition hazards associated with the preventative release of fire extinguishing fluids," stated that although CO_2 is generally thought of as a medium that smothers fire, it can actually be a cause of it by spark discharge when released into flammable materials. He found that the charge buildup that took place when CO_2 was released from a nozzle into a tank was about 100 times that which existed when halogenated hydrocarbons (also non-inflamable) were used instead. But he did have a solution to the CO_2 dilemma by inventing an antistatic CO_2 nozzle some time ago.

Some other subjects treated in this session dealt with an electrostatic charge density monitor in a fuel line; a theoretical paper on the influence of bubbles on electrical breakdown (while in an insulating state they are innocuous, after partial breakdown they will start a catastrophic sequence of instabilities); and an interesting investigation of electrostatically assisted heat transfer. Here J. Cross (Wolfson Electrostatics Advisory Unit, Univ. of Southampton, UK) reported that the application of high electrostatic fields does indeed aid heat transfer from a metal plate through a gas because of a corona wind. At 16.5 kV and 3-cm spacing (see Fig. 2), the velocity of this corona wind was 2 m/sec.

In the invited paper "The role of modern surface analysis techniques and understanding electrification phenomena," in the session entitled Solids, D. Briggs (ICI Ltd., Plastics Division, Welwyn Garden City, UK) stated that electrical breakdown at the surface of a solid can be expected to depend on both macroscopic and microscopic surface structure. He stated, for example, that since electron binding energies for a material such as germanium will be different than for its oxide, breakdown could be expected to depend upon the depth of a surface layer of oxide. Briggs then reviewed a number of surface analytic techniques (e.g., photoelectron spectroscopy, Auger electron spectroscopy, secondary ion mass spectroscopy) and the contributions that they are making to the understanding of electrification phenomena.

Other papers in this session dealt with injection and decay times of charges into polymers, studies of the charge exchange mechanism during triboelectrification, and contact potential. Two papers by the group of Prof. A.C. Rose-Innes (Univ. of Manchester Institute of Science and Technology, Manchester, UK) were of particular interest to me. In one of these, K.P. Homeward and Rose-Innes demonstrated that although the charge transferred from a metal plate pressing onto the surface of a sheet of polytetrafluoroethelene increased linearly with the logarithm of contact time, this increase of contact electrification was not due to any delay in the electron transfer but to an increase in contact area caused by the viscoelasticity of the polymer, and that in any area of contact the charge transfer takes place in a time of 0.3 seconds or less. Even more significant was the second paper, by G.A. Cottrel, C. Reed, and Rose-Innes, in which it was shown that when a metal was contacted to an insulator, contact electrification of the dielectric takes place only if there are impurity states whose energy levels are in the forbidden gap of the insulator. For "pure" dielectrics, achieved in this experiment by condensation of pure rare gases or pure rare gases doped with methane (which does not yield impurity states), there was no charge transfer into the insulator. When doped with chlorine, an electron acceptor, charge transfer occurred.

The final session, Measuring Techniques and Atmospheric Electricity, started with the invited paper "The electrification of thunder storms." This paper, delivered by J. Latham, was a status report of the Thunder Storm Research International Project. Authors were H. Christian, C.R. Holmes, and C.B. Moore (New Mexico Institute of Mining and Technology, Socorro, NM) and W. Gaskell, A.J. Lingworth and J. Latham (Univ. of Manchester, Institute of Science and Technology, Manchester, UK). The objective of this project has been to understand thunderstorms in detail. Interesting results presented were: 1) The presence of solid particles appears to be central to charge transfer. 2) Charging appears to be due to sinking of heavy particles. 3) Lightning in a thundercloud is

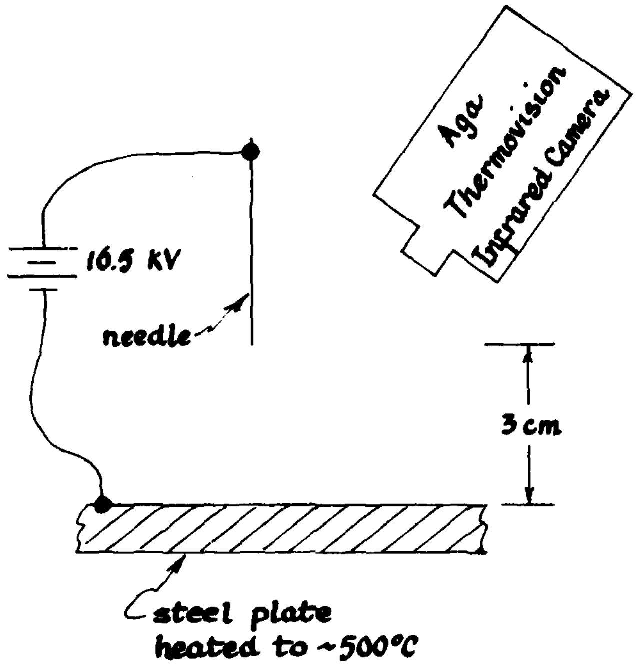

Figure 2

Experiment for observing local temperature changes in steel plate because of corona wind.

initiated at average fields, of only about 4 kV/cm, since the field is strongly intensified locally by the sharp edges of ice crystals.
4) A typical lightning flash neutralizes only about 20 coulombs.
5) The energy in a thundercloud is surprisingly small.

Four other papers dealt with thunderstorms or closely related phenomena. Perhaps of special interest here is a paper by J.L. Boulay (Office National d'Etudes et de Recherches Aérospatiales, Chatillon, France) which was a report of work carried out since 1975 in cooperation with the French Aeronautical Service. Special experimental sites have been set up. Among the experiments performed, rockets were sometimes used for triggering lightning strokes. The objectives were: 1) The characterization of the electric parameters of a triggered stroke discharge, 2) the comparative study of this type of discharge and of natural lightning, and 3) the analysis of strokes within clouds.

I can summarize the conference by stating that to me, personally, this meeting was a revelation. I had not envisioned that electrostatics had become such a live subject, with a number of interesting scientific and practical problems remaining to be solved.

The complete technical program of the Conference was the following:

SESSION I — INDUSTRIAL ELECTROSTATICS - Chairman: Mr E Zichy

INVITED PAPER: THE SCIENTIFIC BASIS OF ELECTRO-PHOTOGRAPHY P K Watson (Xerox Corp., Rochester, USA)

1 LATERAL PROPAGATION OF BACK-DISCHARGE IN TRI-ELECTRODE SYSTEM S Masuda (Univ. of Tokyo) and S Obata (IHI Heavy Industries, Japan)

2 DISCHARGES IN ELECTROSTATICALLY DEPOSITED FILMS Sampuran-Singh, J F Hughes and A W Bright (Univ. of Southampton)

3 AN ANALYTICAL REPRESENTATION OF WEB-ROLLER ELECTRIFICATION K L Clum (Eastman Kodak, USA)

4 ELECTRICAL CHARGING AND DISCHARGING BETWEEN FILM AND METAL ROLLERS J F Hughes, A M K Au (Univ. of Southampton) and A R Blythe (ICI, Welwyn)

5 ELECTROSTATIC BENIFICATION OF ORES ON THE MOON SURFACE I I Inculet (Univ. of W Ontario, Canada) and D R Criswell (Universities Space Research Association, Houston, USA)

6 NON-WOVEN ELECTRET FIBRE: A NEW FILTERING MATERIAL OF HIGH EFFICIENCY J van Turnhout, J H M Albers (TNO) and W J Hoeneveld, J W C Adamse and L M van Rossen (N V Verto, The Netherlands)

SESSION II — HAZARDS — Chairman: Mr H Strawson (not present)

INVITED PAPER: CHARGING OF JET FUEL ON POLYURETHANE FOAM J T Leonard and W A Affens (Naval Research Laboratory, Washington, USA)

7 THE ENERGY OF ELECTROSTATIC DISCHARGES I Berta and N Gastanek (Technical University of Budapest, Hungary)

8 THE NATURE AND INCENDIARY BEHAVIOUR OF SPARK DISCHARGES FROM THE BODY N Wilson (Shirley Institute, Manchester)

9 INSTRUMENTATION AND TECHNIQUES FOR MONITORING AND ASSESSING ELECTROSTATIC IGNITION HAZARDS J N Chubb and G J Butterworth (UKAEA, Culham, Oxon)

10 THE DETECTION AND CHARACTERISATION OF ELECTROSTATIC SPARKS BY RADIO METHODS G J Butterworth (UKAEA, Culham, Oxon)

11 CHARGES ON POWDERS AND BULKING EFFECTS A R Blythe and W Reddish (ICI, Welwyn Garden City, Herts)

12 STATIC ELIMINATOR FOR DIFFICULT INDUSTRIAL APPLICATIONS P E Secker (Univ. College of No. Wales, Bangor)

13 METHODS OF ASSESSMENT OF ANTI-STATIC PROTECTION OF AIRCRAFT J Taillet (ONERA, France)

14 IGNITION BY ELECTRIC SPARKS E Barreto (Albany,NY,USA)

SESSION III — FLUIDS — Chairman: Professor A W Bright

INVITED PAPER: INTERACTION OF ELECTROSTATICS AND FLUID MOTION J C Gibbings (Univ. of Liverpool)

15 ELECTROSTATIC IGNITION HAZARDS ASSOCIATED WITH THE PREVENTATIVE RELEASE OF FIRE EXTINGUISHING FLUIDS G J Butterworth (UKAEA, Culham, Oxon)

16 THE DESIGN AND PERFORMANCE OF NOVEL ON-LINE ELECTROSTATIC CHARGE DENSITY MONITORS, INJECTORS AND NEUTRALISERS FOR USE IN FUEL SYSTEMS N Denbow (Bestobell Mobrey Ltd) and A W Bright (Univ. of Southampton)

17 STATIC ELECTRIFICATION OF PARTICLES IN TWO-PHASE FLOW IN CHANNELS R Kuczynski and A Przekwas (Technical University Wroclaw, Poland) NOT PRESENTED

18 BUBBLES, PARTIAL DISCHARGES AND LIQUID BREAKDOWN N J Felici (Lab. d'Electrostatique, Grenoble, France)

19 INVESTIGATION OF ELECTROSTATIC FIELD PROBLEMS IN THE TRANSPORT AND STORAGE OF LIQUIDS AND POWDERS J Diserens (Rutherford Laboratory) P Lees and J R Smith (Univ. of Aberdeen and A W Bright (Univ. of Southampton) NOT PRESENTED

20 ELECTROSTATICALLY ASSISTED HEAT TRANSFER J A Cross (Univ. of Southampton)

SESSION IV SOLIDS - Chairman: Dr. D K Davies

INVITED PAPER: THE ROLE OF MODERN SURFACE ANALYSIS TECHNIQUES IN UNDERSTANDING ELECTRIFICATION PHENOMENA D Briggs (ICI Plastics, Welwyn Garden City, Herts)

21 PREDICTION OF CHARGED DUST PARTICLE PRECIPTATION IN AN ELECTROSTATIC FIELD IN COMPLEX FLOWS A Przekwas and A Wanik (Technical Univ. Wroclaw, Poland) NOT PRESENTED

22 ON THE CORRELATION BETWEEN DECAY OF CHARGE AND RESISTANCE PARAMETERS OF SHEET MATERIALS N Jonassen, I Hansson and A R Nielsen (Technical University, Denmark)

23 CHARGE EFFECTS AT ALUMINIUM ELECTRODE EDGES ON INSULATING FILMS T J Lewis and R Toomer (Univ. College of North Wales, Bangor)

24 THE EFFECT OF CONTACT TIME ON THE ELECTRIFICATION OF POLYMERS BY METALS K P Homewood and A C Rose-Innes (UMIST, Manchester)

25 INJECTION TIMES FOR CHARGING OF POLYMER SURFACES L Hassmyr and C Backstrom (Univ. Umea, Sweden)

26 CONTACT ELECTRIFICATION OF IDEAL INSULATORS, EXPERIMENTS ON SOLID RARE GASES G A Cottrell, C Reed and A C Rose-Innes (UMIST, Manchester)

27 CONTRIBUTION OF MOLECULAR MOTION OF POLYMER TO FRICTIONAL ELECTRIFICATION K Ohara (Shinshu Univ., Japan)

28 THE CONTACT POTENTIAL AND CHARGE EXCHANGE AT A MERCURY-POLYMER INTERFACE D A Hays (Xerox, Rochester, USA)

After Dinner Talk - Professor J Felici (CNRS, Grenoble) FROM SPLIT SECOND TO AEONS - THE ELECTRIC SPARK, AN IMAGE OF LIVING EVOLUTION AND HUMAN HISTORY

SESSION V MEASURING TECHNIQUES AND ATMOSPHERIC ELECTRICITY - Chairman: Dr J Chubb

INVITED PAPER: THE ELECTRIFICATION OF THUNDERSTORMS J Latham (UMIST, Manchester)

CONTRIBUTIONS

29 MONITORING SYSTEMS FOR ELECTROSTATIC COATING PLANT P E Secker (University College of North Wales, Bangor)

30 A NEW APPARATUS FOR THE MEASUREMENT OF THE RESISTIVITY OF A PARTICULATE LAYER UNDER CONDITIONS OF IONIC BOMBARDMENT G S P Castle and S R M Yelle (Univ. of W Ontario, Canada)

SESSION V (cont)

31 LABORATORY MEASUREMENTS OF CHARGE SEPARATION ASSOCIATED WITH SECONDARY ICE CRYSTAL PRODUCTION C P R Saunders (UMIST, Manchester) and J Hallet (Desert Research Institute Reno, USA)

32 STATIC ELECTRIFICATION IN THE ATMOSPHERE BY THE ELECTROLYTIC PROCESS L Wahlin (Colutron Research Corporation, Colorado, USA)

33 POSITIVE STREAMER VELOCITIES IN QUASI-UNIFORM ELECTRIC FIELDS A S Sadik, J A Bicknell and J Latham (UMIST, Manchester)

34 MEASUREMENT AND LOCALISATION OF ELECTROSTATIC CHARGES NEUTRALISED DURING A LIGHTING STROKE J L Boulay (ONERA, France)

I have been informed that the Proceedings of this Conference may be purchased by writing to Mrs. Audrey Gale, The Institute of Physics, Techno House, Redcliffe Way, Bristol BS1 6NX, UK.

APPENDIX

Since preparing this report, I have learned of the sad news of the death of Professor A.W. Bright. Bill Bright was the leader and driving force of the electrostatics efforts at the University of Southampton, where he was Professor of Electrical Engineering during the last ten years. He is well known for his contributions in the field of electrostatics, in particular to problems relating to safety and to powder coating. He was 54 years old at the time of his passing. His death leaves a significant gap in the community.